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Foreword

Adaptive prescribed burning in Australia for the early 21st Century – context, status, challenges

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Abstract. Despite evident advances in knowledge and understanding concerning the application of prescribed burning for delivering benefits in wildfire control and a variety of sociocultural, economic and environmental outcomes, the practical application of prescribed burning in Australia is increasingly administratively and logistically complex, often controversial and climatically challenging. This series of papers does not address the merits or otherwise of prescribed burning – we accept the lessons from antiquity and recent history that the use of prescribed fire in contemporary Australia is essential for reducing, although not always being able to deliver on, wildfire risks and meeting a variety of societal and environmental needs. This special issue focuses on several fundamental adaptive management and monitoring questions: are we setting appropriate management targets? Can these targets and associated indicators be readily measured? Can we realistically deliver on those targets? And if so, what are the costs and/or trade-offs involved? The 10 solicited papers included here provide a sample illustration of the diversity of approaches currently being undertaken in different Australian regions to address complex adaptive management and monitoring challenges.

Additional keywords: adaptive management, adaptive monitoring, fire management, fire regimes.

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Introduction

The application of prescribed burning for a variety of landscape-scale management purposes has an ancient tradition in Australia. From the arrival of people at least 65 000 years ago (Clarkson *et al.* 2017), landscape burning doubtless was applied to fashion habitats and facilitate hunting and deployed in all manner of cultural activities. Indigenous burning has been implicated in the demise of megafauna (e.g. Flannery 1994; Miller *et al.* 2005*a*; Johnson *et al.* 2016; Saltré *et al.* 2016) and changed habitat conditions (e.g. Singh *et al.* 1981; Miller *et al.* 2005*b*), although these putative impacts need to be appreciated in the context of precarious Late Tertiary climate variability (Price *et al.* 2011; Sakaguchi *et al.* 2013; Wroe *et al.* 2013; Cohen *et al.* 2015). Prehistoric burning practices, and the scales over which these were applied, doubtless also have changed markedly through time. For example, given the changes in occupation patterns, population sizes, technological development and mobility evident in the archaeological record since the mid-Holocene (i.e. the last ~5000 years), the continental patterning and application of burning practices are likely to have developed only over the past few thousand, especially the last 1500 years (Smith 2013; Williams *et al.* 2015).

The historical and artistic record associated with early (late 18th–mid 19th Century) European settlement provides us with limited, mostly localised, occasionally regional, typically tantalising glimpses of Indigenous (Aboriginal) people's burning practices and associated vegetation conditions at that time. Most prescient was the explorer Thomas Mitchell (1848, p. 412), who, after various expeditions through what is now central-western New South Wales, famously observed that 'fire, grass, kangaroos, and human inhabitants, seem all dependent on each other for existence in Australia'. Revisiting that record, it is only in recent decades that the magnitude and complexity of Indigenous landscape management and modification have begun to be recognised (Nicholson 1981; Pyne 1991; Bowman 1998), especially that associated with agricultural economies in prehistoric temperate south-eastern and south-western Australia (Hallam 1975; Benson and Redpath 1997; Abbott 2003; Gott 2005; Gammage 2011; Pascoe 2014; Jurskis 2015). Reconstructions of traditional Indigenous landscape burning practices based on historical accounts have been undertaken also for relatively less modified landscapes in central (Kimber 1983), and especially northern Australia (Braithwaite 1991; Fensham 1997; Crowley and Garnett 2000; Vigilante 2001; Preece 2002).

In addition to these historical accounts, there is a rich ethnographic record, especially for remote and relatively culturally intact central (Gould 1971; Kimber 1983; Latz 1995; Bird *et al.* 2005; Burrows *et al.* 2006; Bliege Bird *et al.* 2008, 2012) and northern Australia (Thomson 1949; Jones 1975, 1980; Crawford 1982; Haynes 1985; Russell-Smith *et al.* 1997, 2003; Bowman *et al.* 2001, 2004; Vigilante *et al.* 2009), including growing numbers of Indigenous perspectives (Yibarbuk 1998; Yibarbuk *et al.* 2001; Garde *et al.* 2009; McGregor *et al.* 2010; Ansell *et al.* 2020; McKemey *et al.* 2020). By contrast, and despite growing recognition of and interest in Indigenous fire knowledge traditions (e.g. Ens *et al.* 2017), it is salutary that similarly detailed records of Indigenous landscape burning practices are not readily available for vast areas of southern, especially south-eastern, Australia.

Much of our contemporary understanding of the cultural and ecological significance of Indigenous fire regimes is indebted to Rhys Jones' (1969) seminal paper, 'Fire-stick farming'. Jones queried the view prevalent at that time that the Australian landscape was 'natural'; instead, he posited that contemporary Australia has been substantially modified (farmed), particularly through the agency of fire. Resonant with contemporary views concerning the importance of prescribed burning for managing fuel loads, the act of undertaking extensive Indigenous landscape burning can also be understood as an obligation for 'cleaning up the country' (Jones 1980; Haynes 1985; Pyne 1991; Lewis 1994).

Remarkably, the emergence of contemporary institutional approaches to prescribed burning in Australia only slightly preceded the belated recognition of the significance of Indigenous landscape fire management. In south-western Australia, several high-intensity fires in valuable northern jarrah (*Eucalyptus marginata*) forest in the late 1950s, followed by the devastating fires of 1961, catalysed development of broad-scale fuel reduction burning techniques (Rodger 1961), including aerial ignition applications (Underwood 2015), building on the pioneering fire behaviour research of Alan McArthur (1962). Since that time, significant advances have been and continue to be made in our understanding of landscape fire management requirements, including the following influential compendia: *overviews and perspectives* – national: Luke and McArthur (1978), Pyne (1991), Cary *et al.* (2003), AFAC (2016); regional – south-west Australia: Abbott and Burrows (2003); southern forests: Adams and Attiwill (2011); central Australia: Latz (2007); northern Australia: Dyer *et al.* (2001), Russell-Smith *et al.* (2009); *fire behaviour* – forests: Gould *et al.* (2007); grasslands: Cheney and Sullivan (2008); *fire ecology and biodiversity conservation* – Gill *et al.* (1981), Whelan (1995), Bradstock *et al.* (2002, 2012*a*), Abbott and Burrows (2003), Gill (2008).

Despite these evident advances in knowledge and understanding, the practical application of prescribed burning in Australia is increasingly administratively and logistically complex, often controversial, and climatically challenging, especially in high-fire-risk, more densely settled southern regions. The series of papers included in this special issue does not address the merits or otherwise of prescribed burning – we accept the lessons from antiquity and recent history that the use of prescribed fire in contemporary Australia is essential for addressing, although not always being able to deliver on, reducing wildfire risks and meeting a variety of societal and environmental needs. Based on this collective experience, our purpose rather is to ask several fundamental adaptive management and monitoring questions: are we setting appropriate management targets? Can these targets and associated indicators be readily measured? Can we realistically deliver on those targets? And if so, what are the costs and/or trade-offs involved? As context for the special issue, the remainder of the present paper describes the development of current institutional arrangements underpinning prescribed burning policy in Australia, addresses an adaptive framework for guiding prescribed burning applications, and introduces the contributed papers and themes these address.

The development of institutionalised prescribed burning in Australia

Development of the modern era of prescribed burning in Australia has been described in various authoritative accounts, notably including RH (Harry) Luke and Alan McArthur's landmark 1978 *Bushfires in Australia* (Luke and McArthur 1978), and Stephen Pyne's (1991) contextual masterpiece, *Burning bush: a fire history of Australia*. The short summary following draws heavily on these works, along with other references as cited. Our focus here is particularly on southern Australia given the impact of those developments nationally.

Following the early colonial period, where often very extensive, but typically uncoordinated, burning was undertaken by early European colonists for land-clearing and pastoral management purposes, institutionalised approaches to fire management essentially can be traced to the formation of southern State-based forestry agencies in the early decades of the 1900s established for the purposes of securing, protecting and nurturing the natural forest estate and for developing plantation resources. Informed by then-current international forest fire management practice in other continental settings, over much of the ensuing period extending to the early 1960s, the major emphasis of forest fire management policy focused on attempted fire exclusion through systematic fire protection. From the start, however, it was increasingly recognised, at least by front-line fire control practitioners, that fire exclusion needed to be complemented with protective fire management practices including installation of firebreaks and burning of narrow strips between compartments, and later the broader application of 'controlled burning' to reduce forest floor fuel loads. Western Australia pioneered these early advances (and much prescribed burning expertise subsequently – see McCaw *et al.* 2003) where, from the mid-1920s, the then Conservator of Forests, Stephen Kessell, oversaw implementation of an extensive, often successful, program of 'controlled burning' that involved the setting of frequent low-intensity fires to reduce and 'clean up' fuels in south-western jarrah (*Eucalyptus marginata*) forests. However, practical implementation was limited by inadequate resources and lack of basic fire behaviour understanding. These issues would not be resolved in Western Australia until the mid-1960s (Underwood 2015).

However, forest resource protection proved (and has continued to prove) highly challenging given both the recurring advent of fires from surrounding, often little or unmanaged lands, and

regionally occasional but nationally numerous infernos that have erupted throughout the period of European settlement, especially in southern Australia under characteristic extreme fire weather conditions. Australian settler history and popular imagination is redolent with such holocausts; for illustrative example: Black Thursday, 6 February 1851, where perhaps a quarter of Victoria was burnt; Red Tuesday, 1 February 1898, which consumed large areas of Gippsland and the Otways in Victoria; Black Sunday, 14 February 1926, raging across the entire south-east mountain region from Canberra to Gippsland; Black Friday, 13 January 1939, including monstrous fires from South Australia to Canberra, but especially in mountainous Victoria; Dwellingup, Western Australia, 24 January 1961, which consumed the town as well as several other settlements in prime native forest; Black Tuesday, 7 February 1967, including one fire that incinerated suburbs in Hobart, Tasmania, leaving 62 people dead; Ash Wednesday, 16 February 1983, with over 200 bushfires extending from South Australia to Victoria leaving 75 people dead; Canberra–NSW–Victoria bushfires, January 2003, which collectively burnt over 20 000 km^2 including 70% of the ACT and into the western suburbs of Canberra; Black Saturday, 7 February 2009, involving 400 bushfires across Victoria leaving 180 people dead. Most recently, south-eastern Australia has experienced an extended period of bushfires in the austral spring and summer of 2019–20 that have caused unprecedented disruption to rural and urban communities and the economy, together with environmental damage on a massive scale (see ABC 2020 for a recent summary at the time of writing – March 2020).

Commissions of enquiry relating to two of the above conflagrations are particularly pertinent here. The first of these, the report of the Royal Commission into the Black Friday 1939 fires overseen by Judge Leonard Stretton, proved to be a major reference point for subsequent reform. Stretton's considered but scathing report for the first time sanctioned the necessity for fuel reduction burning (Stretton 1939). In its aftermath, the report also catalysed the promulgation of new bushfire Acts in all Australian jurisdictions and ongoing development of organised volunteer bushfire brigades. The second report, overseen by Royal Commissioner Geoffrey Rodger in addressing the 1960–61 Western Australia bushfire season, reaffirmed the value of regular fuel reduction burning for decreasing fire intensity and forest damage, and assisting firefighting operations (Rodger 1961; McArthur 1962). The report recommended that every endeavour be made to improve and extend controlled burning to ensure the maximum fire protection practicable. In support of that observation, subsequent experience in south-west Western Australia forests has demonstrated a strong inverse relationship between the annual extent of prescribed burning and wildfire occurrence (Underwood *et al.* 1985), with fuel reduction burning having a detectable effect on the incidence and extent of wildfire for up to 6 years (Boer *et al.* 2009; Burrows and McCaw 2013).

Commencing in the 1950s, ongoing development of fuel reduction operations was assisted substantially by national applied fire research programs initiated under the then Forestry and Timber Bureau and the CSIRO. In particular, in the 1960s, reliability and broadacre expansion of the fuel reduction program in southern forested areas was made possible with two key technical breakthroughs. The first of these advances was Alan McArthur's 1962 updated publication, *Control burning in eucalypt forest*, of his fire-danger rating tables that, for the first time, provided a rigorous quantitative tool based on extensive experimental burning under a range of fuel and fire weather conditions for predicting fire behaviour in operational settings. This advance, including the first iteration of practical handheld operational meters to predict fire behaviour under grassland (McArthur 1966) and eucalypt forest (McArthur 1967) 'Fire danger' conditions, heralded ongoing development of prescribed burning guides and fire spread models for grasslands (temperate, tropical and arid), eucalypt forests, shrublands and pine plantations (see Cruz *et al.* 2015 for a comprehensive account).

The second key development concerned successful operational application of aerial ignition technology, first in Western Australia (Baxter *et al.* 1966), enabling the conducting of prescribed burning across extensive areas, including in wet sclerophyll karri forests from 1969 (Underwood 2015). In 1967, the ACT and NSW conducted large-scale aerial ignition trials in rugged terrain in the Brindabella Ranges and demonstrated that low-intensity fire could also be applied successfully in steep terrain. However, broad-scale prescribed burning in the eastern States under steep topographic conditions is typically difficult given erratic weather conditions, particularly in spring, compared with the relatively benign terrain and fire climate of south-west Western Australia. Subsequently, Victoria developed a helicopter-based ignition delivery system that has been found to provide greater flexibility and accuracy for aerial ignition, particularly for flying contour ignition lines (Underwood 2015). Helicopter-based ignition is widely implemented in northern Australian prescribed burning operations (Dyer *et al.* 2001).

By the 1970s, prescribed burning operations focused on fuel (or 'hazard') reduction had achieved a high level of technical proficiency as well as being supported by highly organised rural fire agencies in all jurisdictions (McCaw *et al.* 2003; Morgan *et al.* in press). Luke and McArthur (1978) estimated that, by the mid-1970s, rural firefighting volunteers numbered ~300 000 nationally. In part as response to growing societal awareness and concerns relating to prescribed burning (e.g. Australian Conservation Foundation (ACF) 1970; Fire Ecology Symposium (FES) 1970), the 1960s and 1970s also saw growing attention given to understanding the ecological effects of burning on Australian biota and ecosystems. Australia's first code of practice for fire management on public land was introduced in Victoria in 1965, with updated versions, including for ecological burning purposes, continuing to be developed including for other jurisdictions. Today, our understanding of the ecological effects of fire regimes has developed substantially (e.g. Gill *et al.* 1981; Whelan 1995; Bradstock *et al.* 2002, 2012*a*; Abbott and Burrows 2003). In turn, this has required fire managers to address the twin challenges of delivering the primacy of community protection (as reinforced in recent Commissions of Inquiry, e.g. Teague *et al.* 2010; Keelty 2011), while simultaneously meeting expectations to conserve biodiversity and sustain natural environmental processes. The relative importance placed on these multiple objectives by the community at large and those responsible for delivering fire management continues to fuel vigorous debate (e.g. Pyne 2006; Penman *et al.* 2011; Bradstock *et al.* 2012*b*; Attiwill and Adams 2013; Burrows and McCaw 2013).

Reflecting the general decline of the rural agricultural sector, by 2003 rural bushfire volunteer numbers had shrunk to ~214 000 (McLennan and Birch 2005), slightly more than official numbers of rural agency volunteers recorded on respective websites as at January 2019. This decline in rural volunteer support is indicative also of fundamental changes and challenges to institutionally sanctioned fire management: the massive decline in the status and resources of forest management agencies; the burgeoning urbanisation of Australian society (where, already by the 1980s, 85% of the population were metropolitan residents); associated changes in societal and cultural aesthetic values; increasing popularity for residing in and fragmentation of high fire-risk peri-urban landscapes (often supported by inappropriate local government regulatory provisions); growing awareness of broader ecological, smoke, precarious water resource, Indigenous cultural burning and community risk fire management requisites and complexities; and ultimately, especially in south-eastern Australia, diminishing political will and support for prescribed fuel reduction activities in the face of polarised community positions (Pyne 1991, 2006; Adams and Attiwill 2011; Burrows and McCaw 2013; Enright and Fontaine 2014; Morgan *et al.* in press).

In 2020, these challenges pose significant questions for all who are concerned with delivering effective protective and ecologically sustainable fire management:

- How much or little burning is enough (e.g. Teague *et al.* 2010)? – or is it the case that we need to move on from generic area-based targets to location-specific risk-based assessments and strategic zoning approaches informed by contemporary predictive fire behaviour and ecological modelling tools (e.g. Victoria Department of Sustainability and Environment 2012; Burrows and McCaw 2013; Howard *et al.* 2020; Morgan *et al.* in press)?
- How do we address the public perceptions of residents living in extreme fire hazard situations, especially in the leafy fringes of our major cities, that fuel reduction burning has little or no value – when, in fact, except for terrifying instances where infernos, once unleashed, explode through eucalypt canopies and spot kilometres in advance under catastrophic fire weather conditions, substantial evidence is available to show that, to the contrary, pre-emptive prescribed burning is typically effective in reducing fire intensity and aiding fire suppression activities (e.g. Billing 1981; Underwood *et al.* 1985; Grant and Wouters 1993; McCarthy and Tolhurst 1998, 2001; Fernandes and Botelho 2003; Cheney 2010; Tolhurst and McCarthy 2016; Underwood 2018; Morgan *et al.* in press)?
- How do we make the case, and garner necessary political support for, resourcing the broader implementation of preventative and sustainable fire management in the face of ever-increasing investment in and reliance on expensive suppression activities and assets (e.g. water bombers) – especially given the exacerbating realities of diminishing seasonal opportunities for safe and appropriate implementation of prescribed fuel reduction and ecological burning, and deteriorating fire weather conditions generally (Lucas *et al.* 2007; Keelty 2012; Clarke *et al.* 2013; Hughes and Steffen 2014; Hughes and Alexander 2017; Dowdy 2018; McCaw 2018; Dowdy *et al.* 2019; Morgan *et al.* in press)?

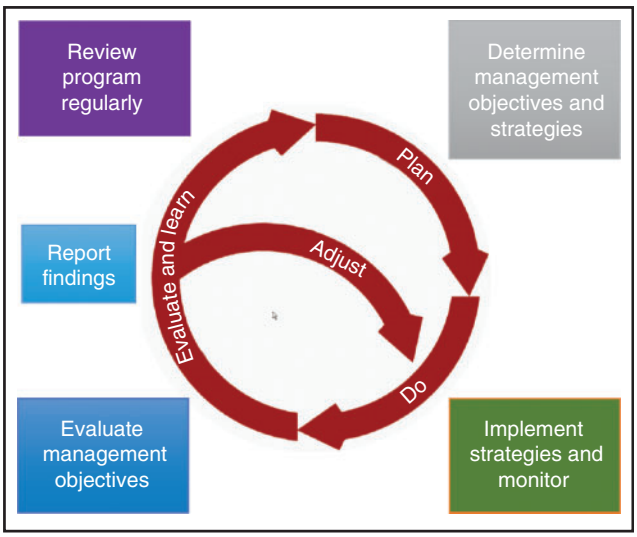

Fig. 1. A widely used schematic illustrating key components of the adaptive management and monitoring cycle.

- How do we better inform and engage with the wider Australian community, and provide appropriate support for those who generously give their time (and sometimes risk their lives) in undertaking essential prescribed fire management, mitigation and control activities?

Continuous adaptive management and monitoring

It is a widely accepted tenet of contemporary landscape fire management practice that the adaptive management and monitoring cycle is an essential requirement for systematically guiding, evaluating and revising management performance (Fig. 1). However, in Australia, despite official recognition of the importance of setting measurable prescribed fire and associated risk management targets and implementing formal performance review processes (e.g. AFAC 2016, 2017), the extent to which this is effectively undertaken by state-based fire management agencies and other practitioners remains equivocal (AFAC 2014) – and, as demonstrated by the papers included in this special issue, is conceptually, practically and continuously challenging.

The papers included here were solicited from colleagues currently involved with researching a variety of prescribed burning activities and issues in different parts of Australia – mostly supported at least in part by Australia's Bushfire and Natural Hazards Cooperative Research Centre. Although the topics covered and geographical settings are diverse, respectively they explore different aspects of the adaptive management and monitoring cycle.

In establishing a national precedent, for the State of Western Australia, Howard *et al.* (2020) describe the development of a comprehensive adaptive management and monitoring framework, albeit untested, for prioritising prescribed burning targets and indicators on public lands throughout that vast state. For relatively densely settled south-east Queensland, and the very sparsely settled rangelands covering two-thirds of Australia,

Eliott *et al.* (2020) and Russell-Smith *et al.* (2020) respectively utilise contemporary fire history mapping products to explore the extent to which targets and indicators, even if loosely defined, currently are being met. Both papers identify practical measures and means for enhancing monitoring, evaluation and implementation delivery.

Three papers present insightful regional case studies for defining and assessing measurable community- and ecological-based targets and indicators. For the Otway Ranges region in southern Victoria, Gazzard *et al.* (2020) describe a thorough structured community engagement approach to 'identify a fuel management strategy that maximises outcomes for social, economic and environmental objectives, while minimising costs'. After over a decade of implementing commercial landscape-scale 'savanna burning' greenhouse gas emissions projects on Indigenous lands in Arnhem Land in the Northern Territory, two contributions assess the extents to which those projects are respectively satisfying cultural aspirations and ecological criteria. Utilising explicit land-use planning goals for five regional projects, Ansell *et al.* (2020) show that, despite annual variability in meeting management targets, cultural aspirations are being substantially met. For the longest-running savanna burning project, covering 28 000 km^2 of western Arnhem Land, Evans and Russell-Smith (2020) demonstrate that, although the regional fire regime has transitioned from wildfire- to now management-dominated and most ecological criteria have improved, substantial ecological challenges remain.

The remaining four papers present modelling simulations to explore the application and cost-effectiveness of prescribed burning treatments for mitigating wildfire risks to assets in southern Australian contexts. For the Sydney region, Price and Bedward (2020) describe a computationally simple and efficient wildfire risk planning procedure to 'quantify and map the probability of fires reaching the vicinity of assets in a wildfire prone region [based on] extending a statistical fire spread model developed on historical fire patterns'. Cirulis *et al.* (2020) apply the Phoenix fire simulator (widely used in south-eastern Australia for predicting fire behaviour) and Bayesian networking to contrast the differential effects of prescribed burning treatment rate on mitigating wildfire risks to assets in wildland–urban interface settings centred on Canberra (Australian Capital Territory) and Hobart (Tasmania). Extending that assessment, Penman and Cirulis (2020) compare potential costs and impacts on assets of different fuel management approaches in the surrounding Canberra region, concluding that the current proposed fuel treatment approach provides 'the greatest reduction in risk and the most cost-effective approach to managing fuels in this landscape'. Finally, Florec *et al.* (2020) model the costs and benefits associated with different landscape and wildland–urban interface fire management treatments on public lands in the south-west of Western Australia. Their critical assessment concludes that, in most cases, prescribed burning treatments focused on the wildland–urban interface do not provide the most economically efficient strategy.

The above papers provide a sample illustration of the diversity of approaches currently being taken in different Australian regions to address complex adaptive management and monitoring challenges posed by, and associated with, the application of prescribed burning in diverse societal and environmental settings. As noted, the magnitude of these challenges is set to increase markedly in the decades ahead given ongoing urbanisation, accountability requirements and deteriorating climatic conditions. Equally, adaptive fire management and monitoring will require us to continuously ask: are we setting appropriate management targets? Can these targets and associated indicators be readily measured? Can we realistically deliver on those targets? And if so, what are the costs and/or trade-offs involved?

Conflicts of interest

The authors declare that they have no conflicts of interest.

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